Cloud Trends Obtained from CALIPSO, CloudSat, and MODIS Observations

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Questions

- How differently do MODIS passive and CALIPSO/CloudSat active sensors observe cloud amounts in a short-term period?
- Can we get reliable long-term cloud trends from active sensors (CALIPSO and CloudSat) since the instruments were not designed such a long period?
- How different are the long-term cloud trends detected from MODIS and CALIPSO/CloudSat?

Datasets (2007–2017, Daytime)

- **MODIS clouds**
  - ✓ Cloud mask is from CERES Ed4 SSF product.
  - ✓ Up to two MODIS cloud types per CERES footprint

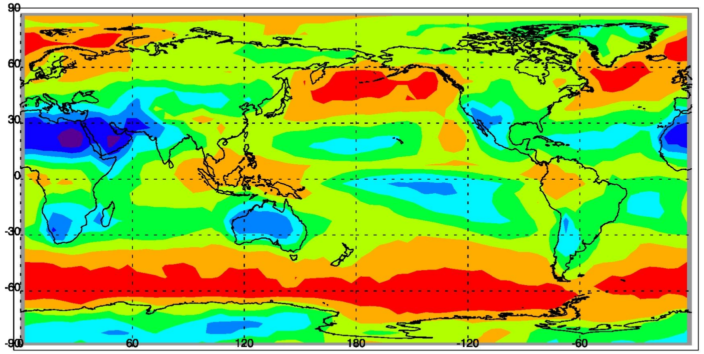
- **CALIPSO clouds**
  - ✓ Cloud mask is from CALIPSO V4 vertical feature mask (VFM) product
  - ✓ Cloud aerosol discrimination (CAD) score ≥ 70
  - ✓ Ice clouds are from all scales of horizontal averaging.
  - ✓ Water clouds < 4 km are from a single lidar beam only.
  - ✓ Water clouds ≥ 4 km or unknown phase clouds are from all scales of horizontal averaging.

- **CloudSat clouds**
  - ✓ Cloud mask is from CloudSat 2B-GEOPROF R05 product with a threshold value of 30 (cloud mask value ≥ 30; 0 = clear, 40 = cloudy).

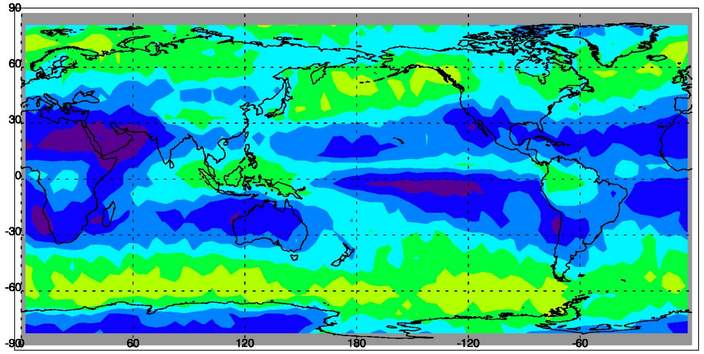
- **CALIPSO+CloudSat (CALCS) clouds**
  - ✓ Cloud layers from CALIPSO and CloudSat are merged.

Total Cloud Fractions (Horizontal Coverages of Clouds) Observed for One Year (2008)

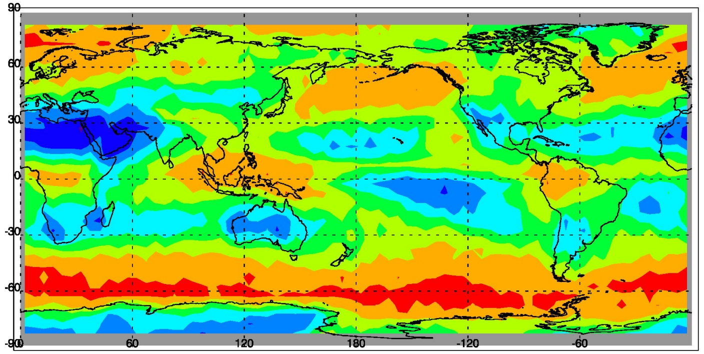
MODIS (Glo Mean: 65.1%)



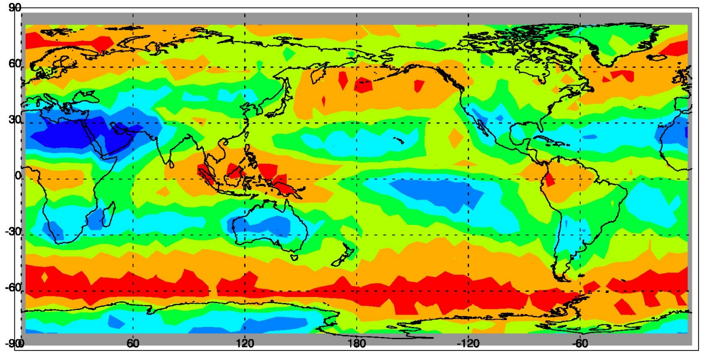
CloudSat (Glo Mean: 39.0%)



CALIPSO (Glo Mean: 61.9%)



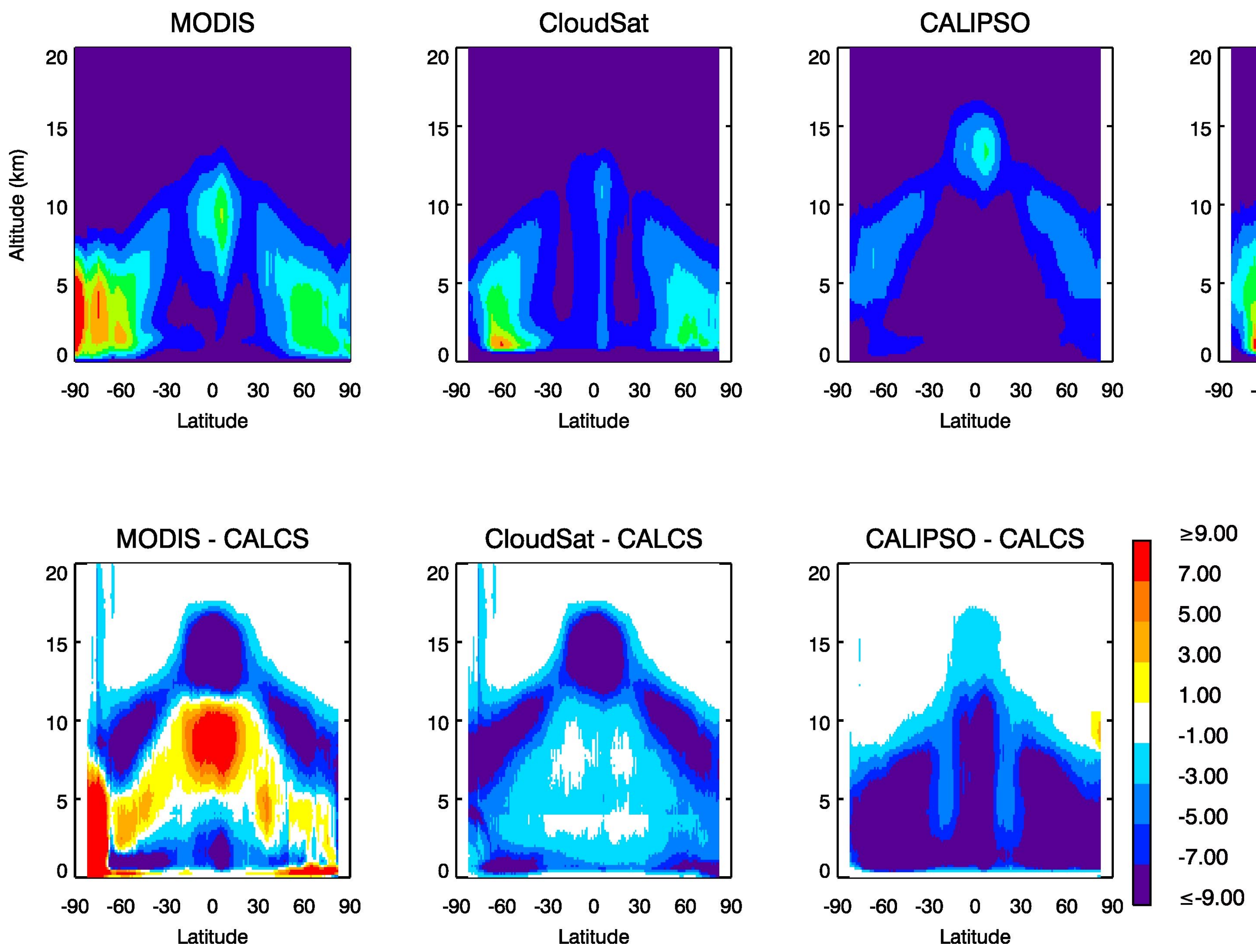
CALCS (Glo Mean: 64.3%)



Total Cloud Fraction (%)

- Horizontal cloud coverages from MODIS, CALIPSO, and CALCS are comparable.
- CALIPSO might miss cloud bottom parts, but it detects most of cloud tops.
- CloudSat cloud coverage is much smaller than MODIS or CALCS due to the missed entire low clouds → Importance of combining CALIPSO and CloudSat.

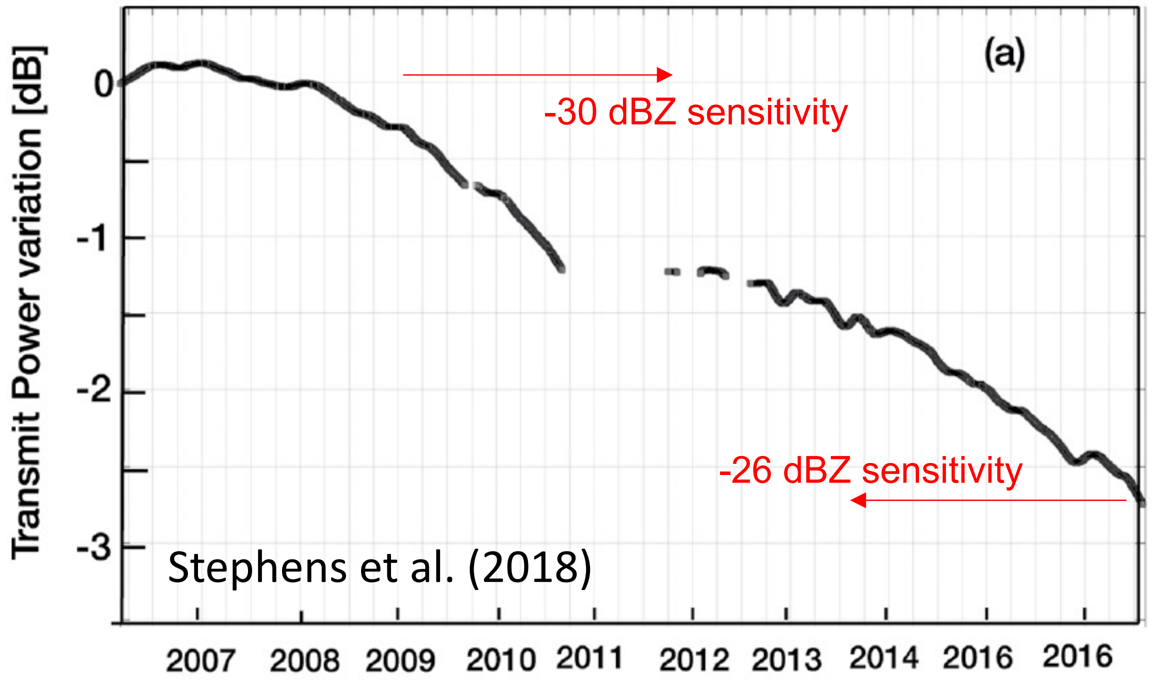
Cloud Occurrences (%) by Vertical Layers for One Year (2008)



- MODIS tends to detect more mid-level clouds and less high-level clouds, but the differences are compensating.
- CloudSat underestimates high-level and low clouds < 1 km.
- CALIPSO underestimates low and mid-level clouds.

CloudSat Sensor Changes for the Observing Period (Stephens et al. 2018)

- Output power of the CloudSat CPR radar has degraded at about a rate of 0.2 dB yr^{-1} for 2012-2014, and at a rate of 0.5 dB yr^{-1} in the later period. As a result, the minimum detectable radar reflectivity is increased from –30 dBZ to –26 dBZ over time.



The power is scaled between 0 (beginning of mission) and −4, which roughly corresponds to −30- to −26-dBZ sensitivity.

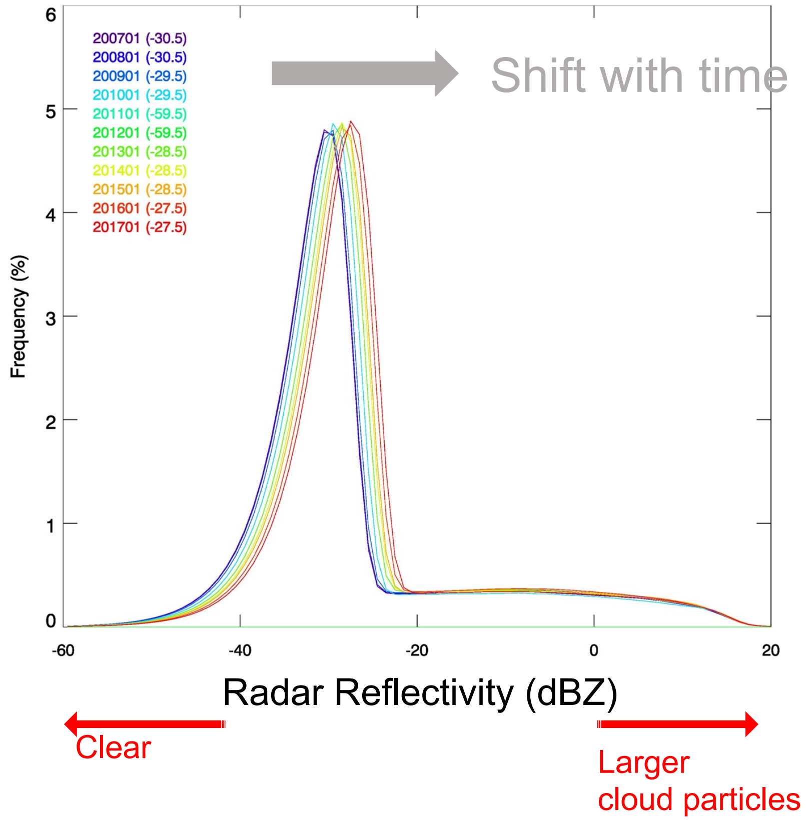
- As a result, clouds with a small radar reflectivity (< -25 dBZ) would be missed more over time.

Distributions of CloudSat 2B-GEOPROF R05 Radar Reflectivity (Z_{dB} = 10 log Z) over Time (60S–60N)

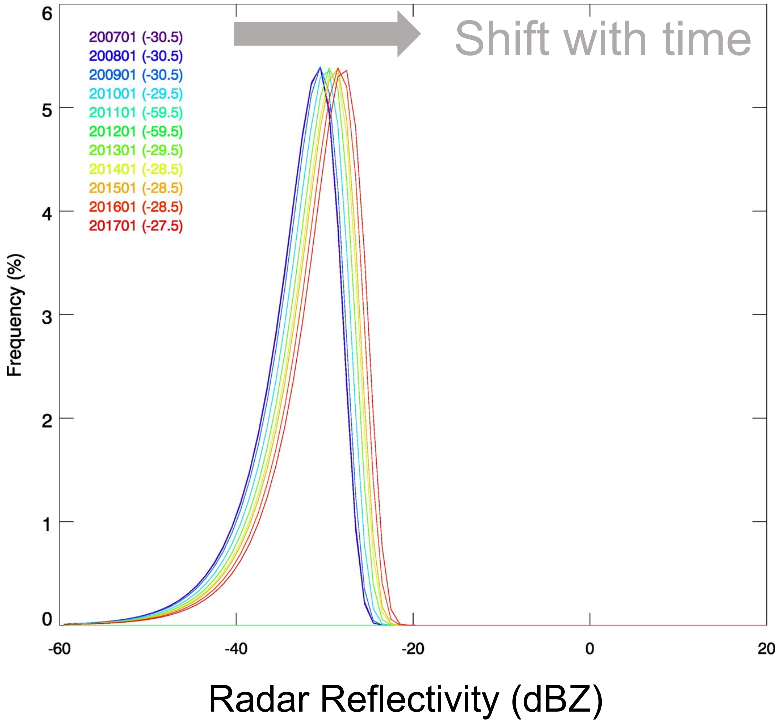
January

- ✓ Radar reflectivity (Z; $mm^6\ m^{-3}$) is proportional to $N(D)D^6$.
- ✓ As the cloud particle is larger or the number concentration is larger, the radar reflectivity (Z or Z_{dB}) increases.

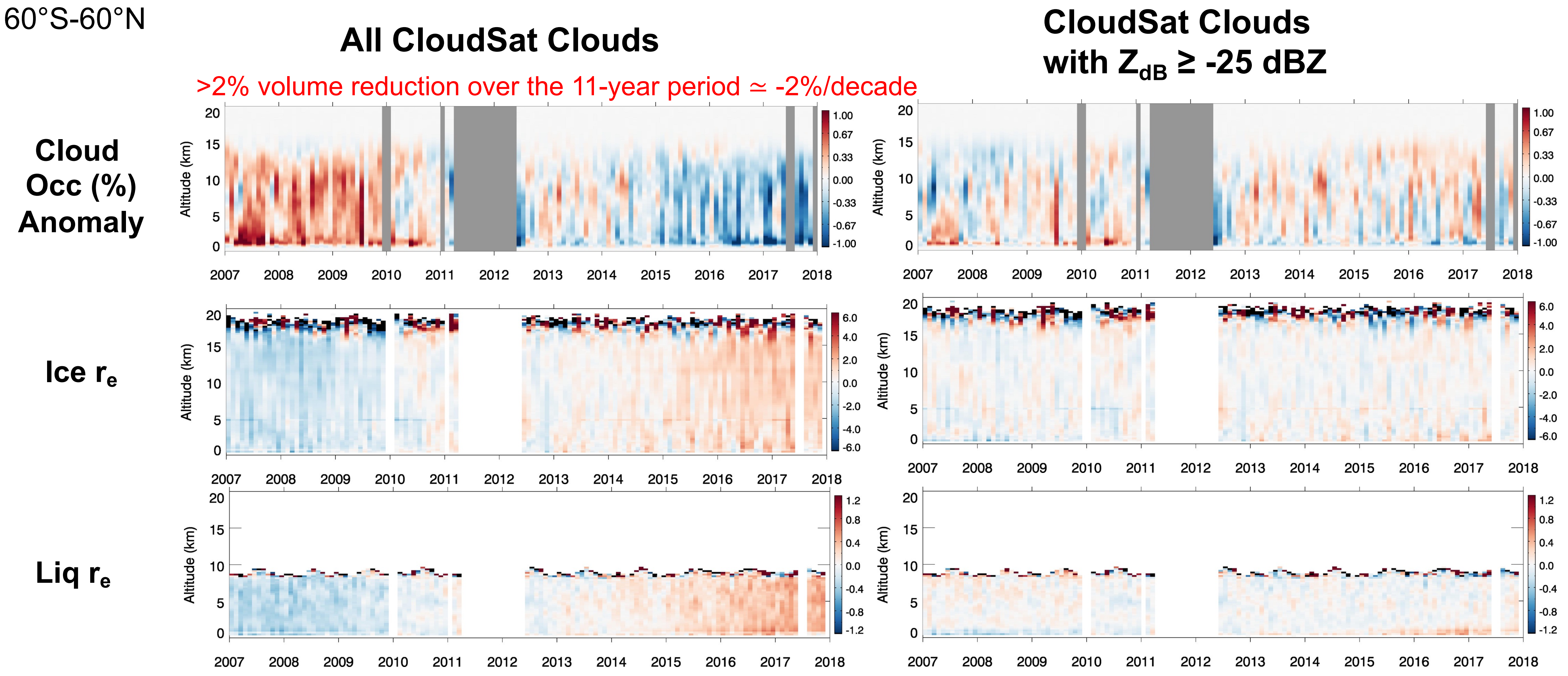
4-8 km



20-24 km

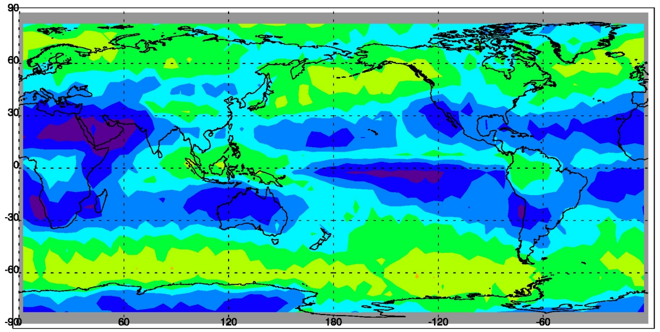
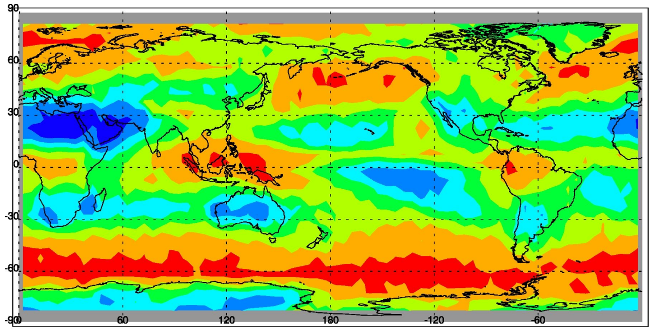
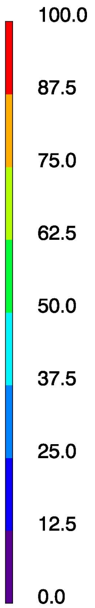
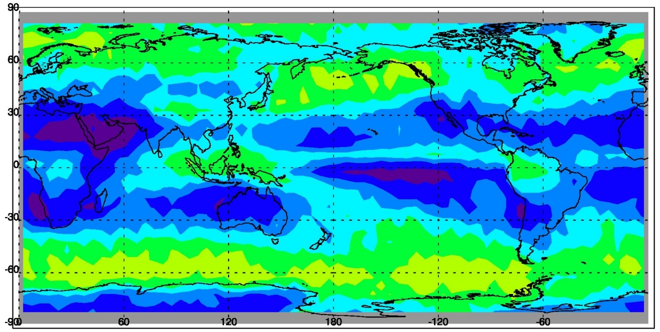
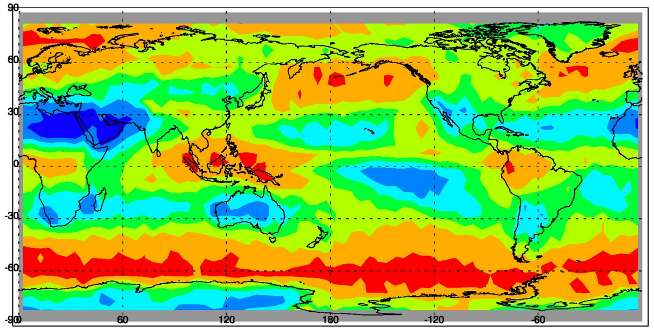
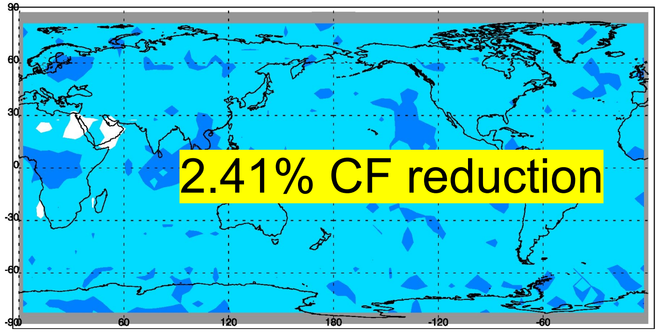
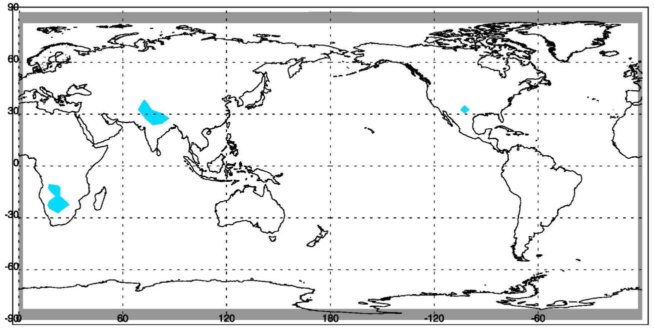
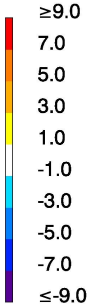


- Z_{dB} for clear skies shifted to a larger value over time. This is due to the change of the minimum output power of CPR.
- It seems that the maximum value (cloud regions) of Z_{dB} remains similar over time. It is still needed to examine the impact on the retrieved cloud properties.



- As the minimum output power of CloudSat sensor has decreased over time, more thin clouds consisting of small cloud particles has been excluded (Mathew Lebsock, personal communication). The exclusion of such clouds also results in spurious increasing cloud particle size trend.
- When the thin clouds with small reflectivity (Z_{dB} < -25 dBZ) was excluded throughout the period, according to CloudSat team's suggestion (Matthew Lebsock), the spurious trends are removed.

Impact of Removing Clouds with Z_{dB} < -25 dBZ on Total Cloud Fractions (Year 2008)

	CloudSat	CloudSat+CALIPSO	
All CloudSat Clouds	CloudSat (41.4 %) 	CALCS (64.6 %) 	
CloudSat Clouds with $Z_{dB} \geq$ -25 dBZ	CloudSat -25 dBZ (39.0 %) 	CALCS -25 dBZ (64.3 %) 	
Diff	CS-25dBZ minus CS (–2.41 %) 	CC-25dBZ minus CC(–0.31 %) 	

- By excluding CloudSat clouds with Z_{dB} < -25 dBZ, CloudSat total cloud fraction is reduced by 2.4%.
- The impact of excluding small reflectivity (Z_{dB} < -25 dBZ) is smaller in CALCS total cloud fractions since CALIPSO supplements the removed CloudSat clouds.

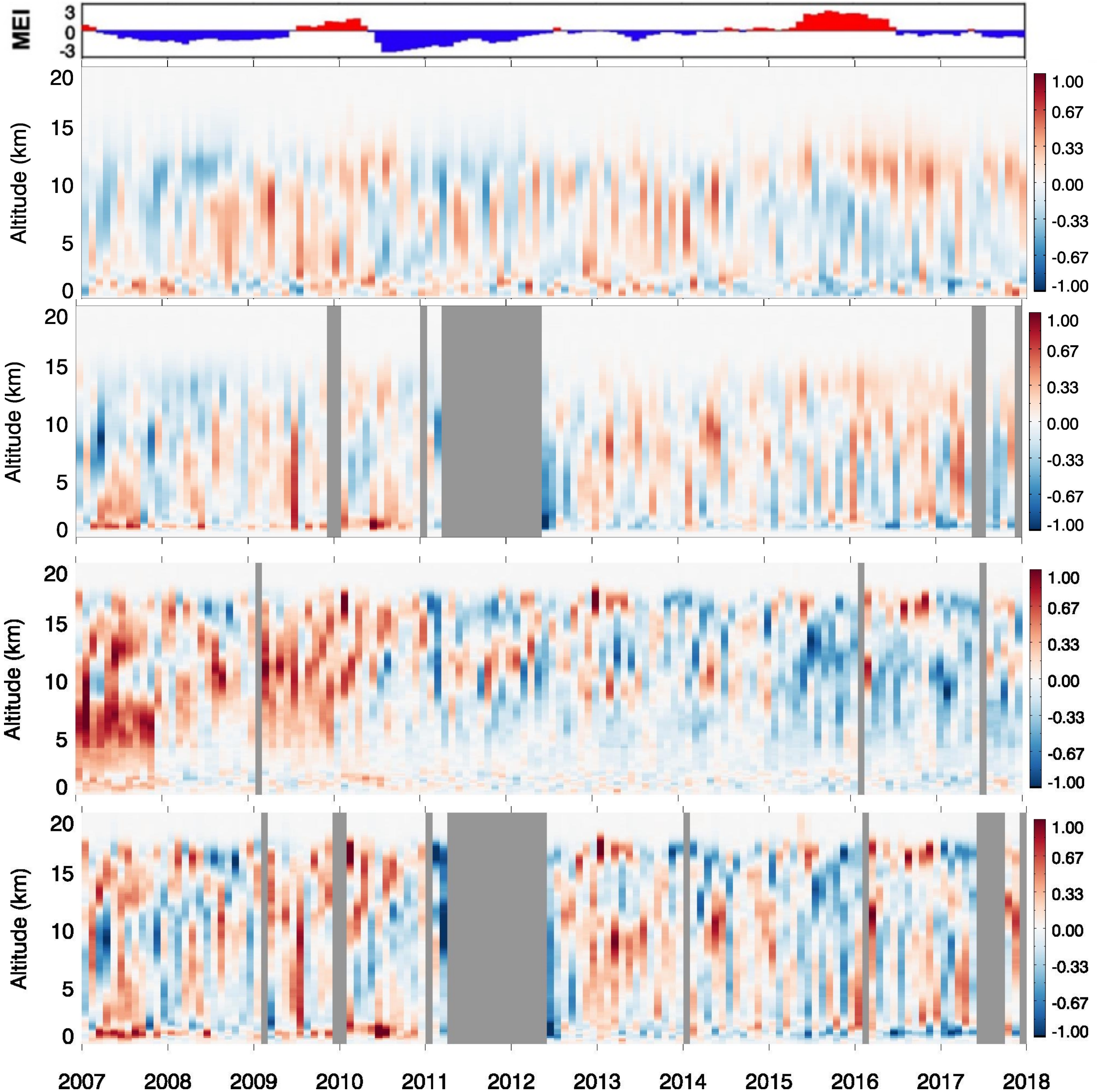
Cloud (Volumetric Fraction Mean) Occurrence Anomalies (%) over 60°S–60°N

MODIS

CloudSat

CALIPSO

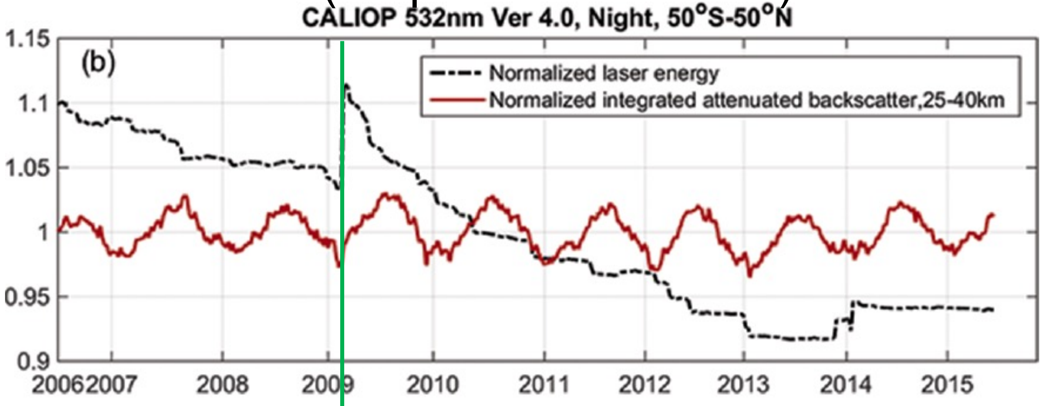
CALCS

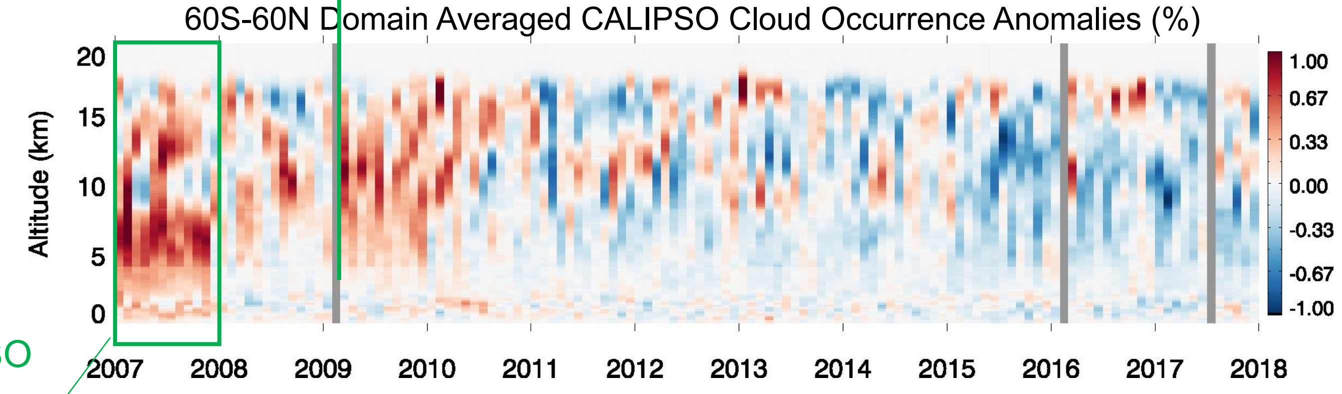


- A decreasing trend is noted in the CALIPSO cloud volume anomalies.
- MODIS and CloudSat do not show a decreasing trend.
- CALCS shows smaller decreasing cloud anomalies, but high clouds are mostly from CALIPSO and a decreasing trend is noted.
- The CALIPSO decreasing trend might be due to 1) real cloud changes of optically thin cirrus clouds, or 2) sensor degradation.

CALIPSO Sensor Changes for the Observing Period (Stephens et al. 2018)

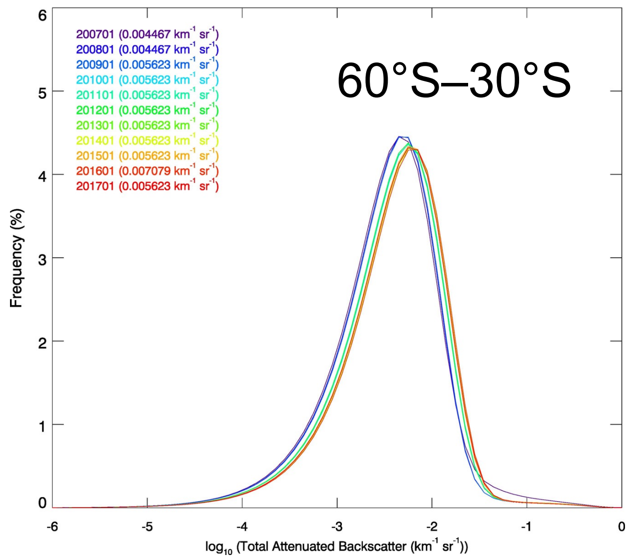
(Stephens et al. 2018)





Before CALIPSO viewing angle changes

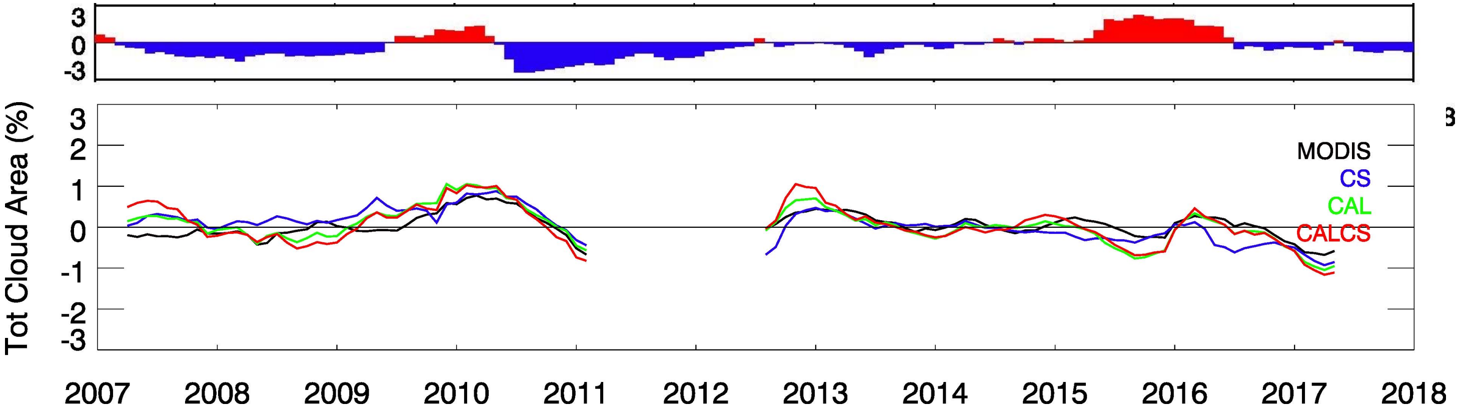
Distribution of CALIPSO V4.1 Total Attenuated Backscatter at 532 nm (km^{-1} sr^{-1}) at 4-8 km



- Similar to CloudSat, the background signal has increased over time, particularly around after 2010-2011.

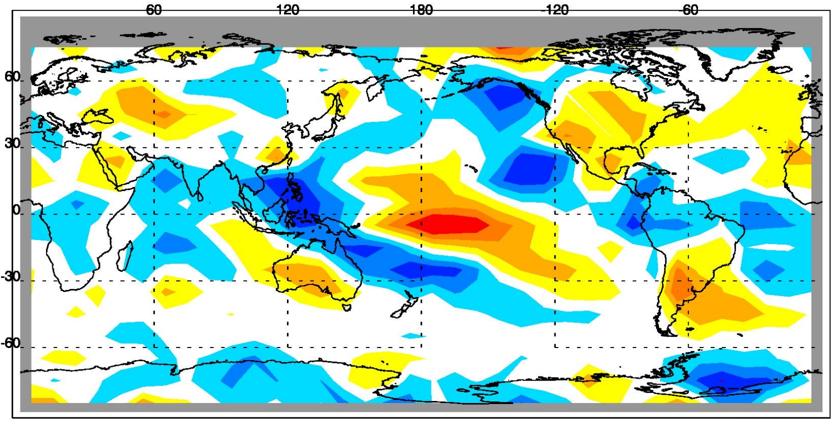
- CALIPSO was designed with two redundant laser transmitters. The first laser was switched with the second laser in March 2009. The second laser started to fail starting summer of 2017.
- The CALIPSO laser pulse energy has degraded but the calibrated backscatter has been stable over time.
- However, slightly decreasing cloud is noted in CALIPSO cloud volume since 2009, further requiring investigation.

Total Cloud Fraction Trend for 2007–2017 (%/decade)



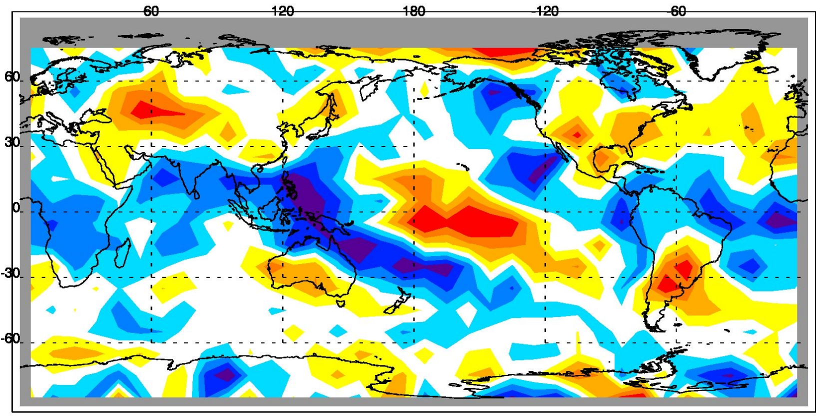
MODIS

Trend (Glo Mean: -0.1±0.6 %/decade)



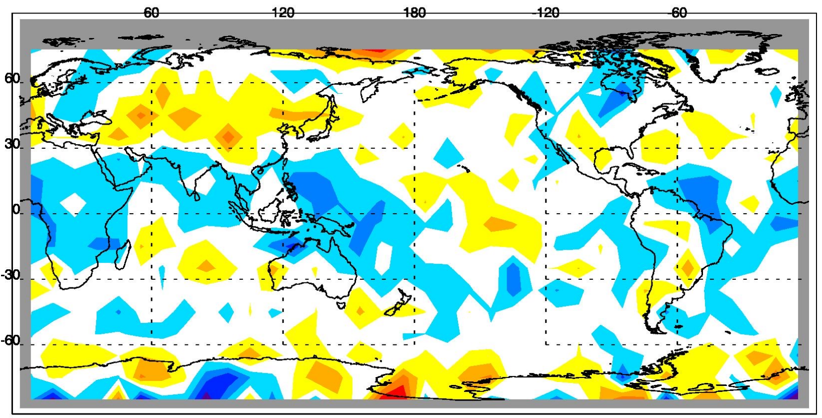
CALCS

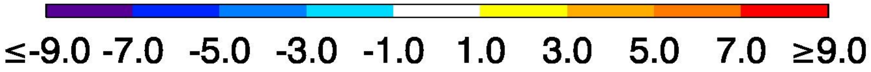
Trend (Glo Mean: -0.3±1.2 %/decade)



CALCS – MODIS

ΔTrend (Glo Mean: -0.1±0.8 %/decade)



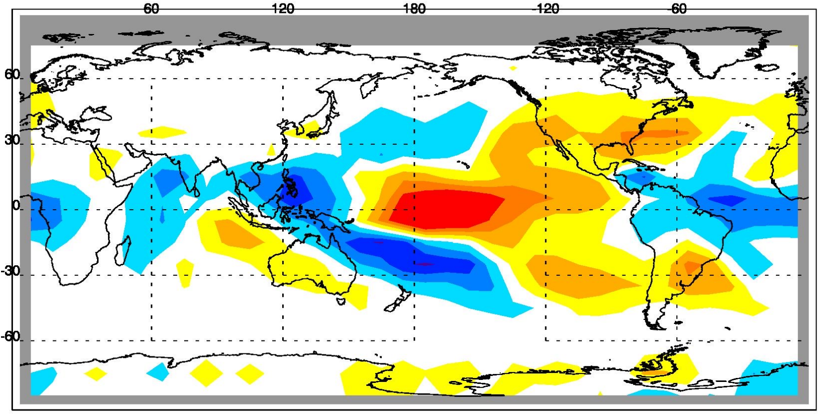


- Strong 2015-2016 El Nino event in the later period and most of spatial distributions of total cloud anomalies reflect El Nino features.
- Both MODIS and CALCS indicate increase of clouds over the central Pacific and decrease of SPCZ. However, CALCS indicates a larger decrease over the SPCZ, mostly due to CALIPSO cloud information.

High (Top at 10-18km) Cloud Trend for 2007–2017 (%/decade)

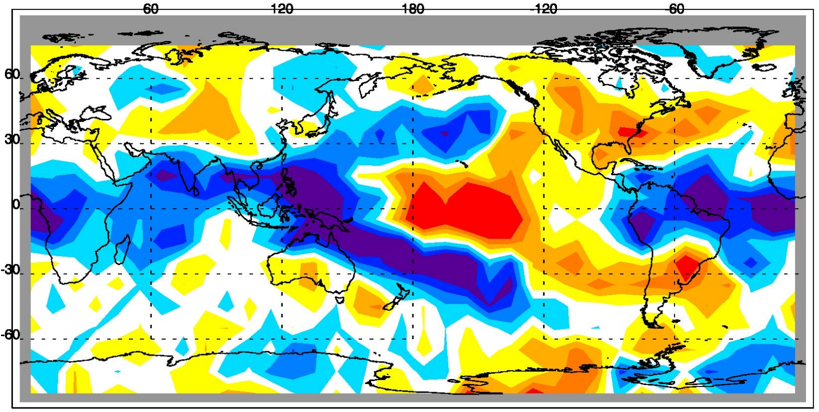
MODIS

Trend (Glo Mean: 0.4±0.5 %/decade)



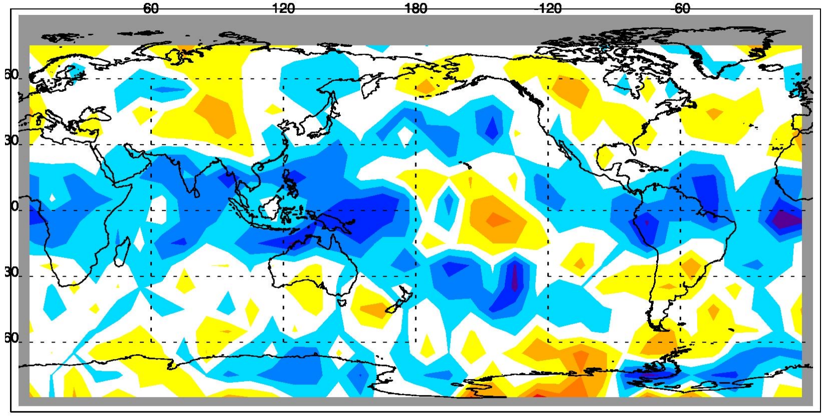
CALCS

Trend (Glo Mean: -0.5±1.3 %/decade)



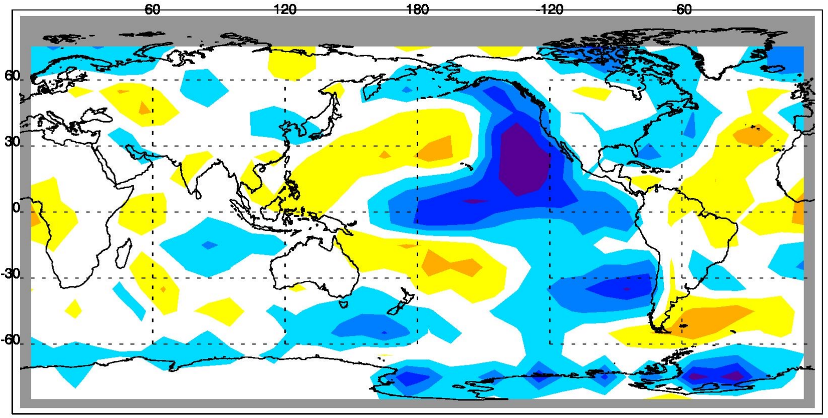
CALCS – MODIS

ΔTrend (Glo Mean: -0.8±1.2 %/decade)

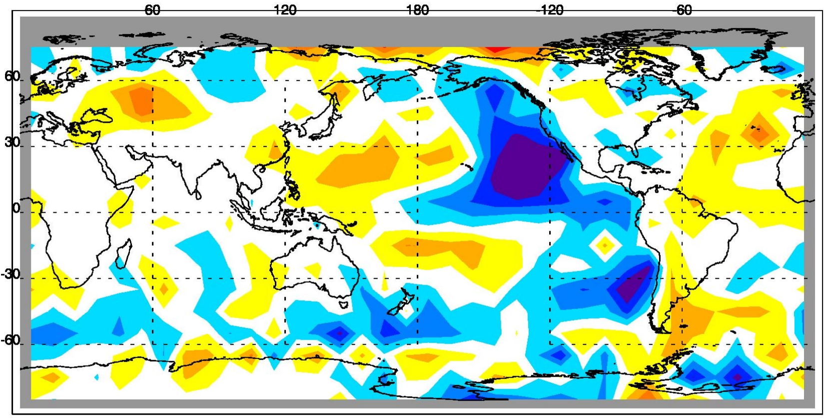


Low (Top < 3km) Cloud Area Trend for 2007–2017 (%/decade)

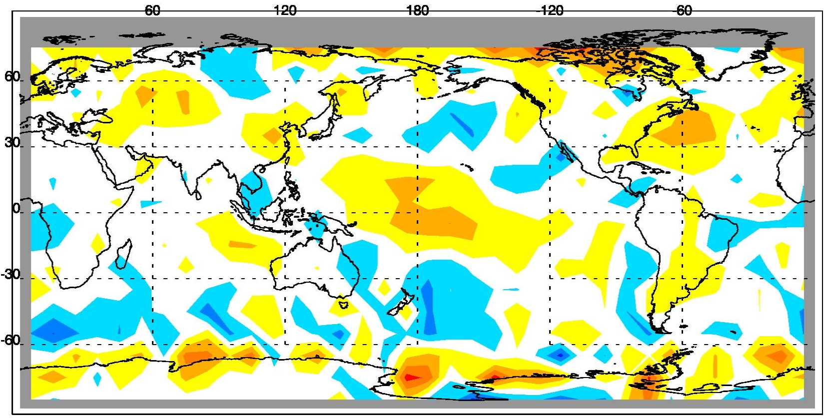
Trend (Glo Mean: -0.5±0.4 %/decade)

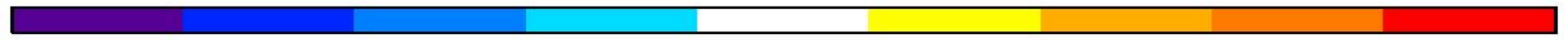


Trend (Glo Mean: -0.1±0.5 %/decade)



ΔTrend (Glo Mean: 0.4±0.7 %/decade)





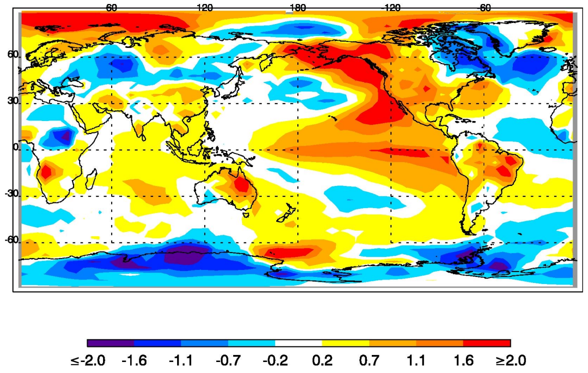
≤-9.0 -7.0 -5.0 -3.0 -1.0 1.0 3.0 5.0 7.0 ≥9.0

Any Clues about the High Cloud Changes from Meteorological Conditions?

MERRA-2 Trend (2007-2017)

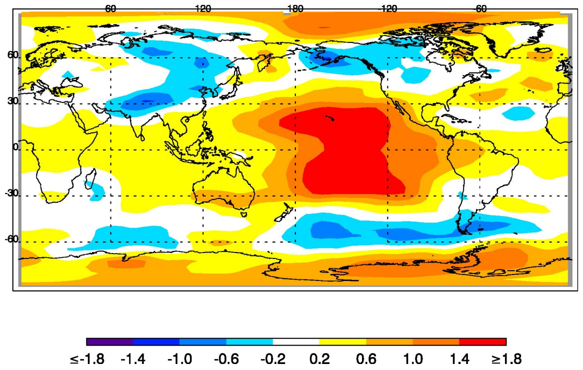
Skin Temp (K)

Trend (Glo Mean: 0.3±0.2 K/decade)



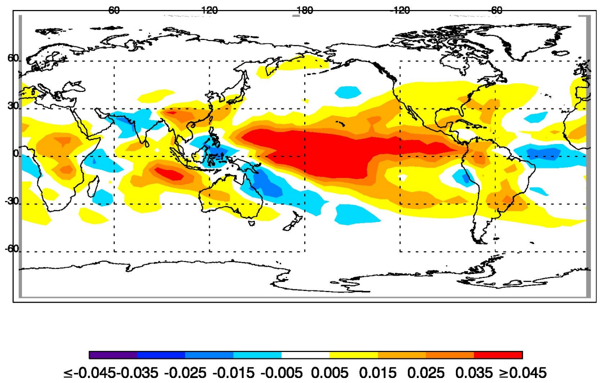
250-hPa Temp (K)

Trend (Glo Mean: 0.4±0.3 K/decade)



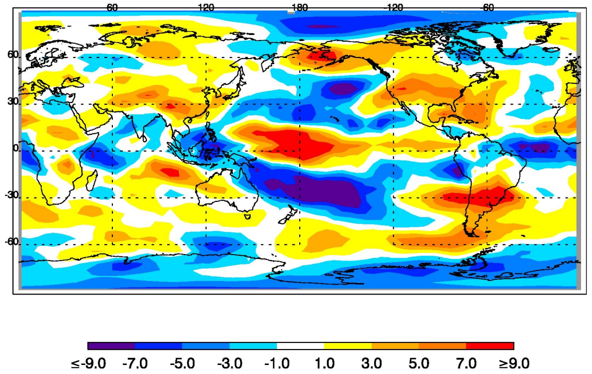
250-hPa Specific Humidity (g/kg)

Trend (Glo Mean: 0.007±0.006 g kg^{-1}/decade)



250-hPa RH (%)

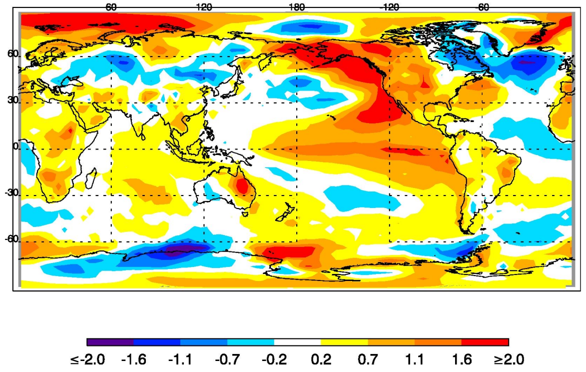
Trend (Glo Mean: 0.3±1.0 %/decade)



ERA-5 Trend (2007-2017)

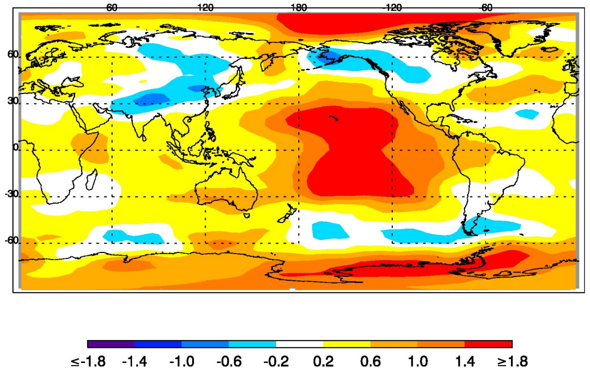
Skin Temp (K)

Trend (Glo Mean: 0.3±0.2 K/decade)



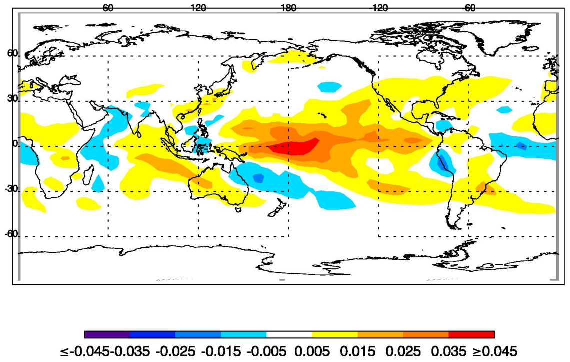
250-hPa Temp (K)

Trend (Glo Mean: 0.5±0.3 K/decade)



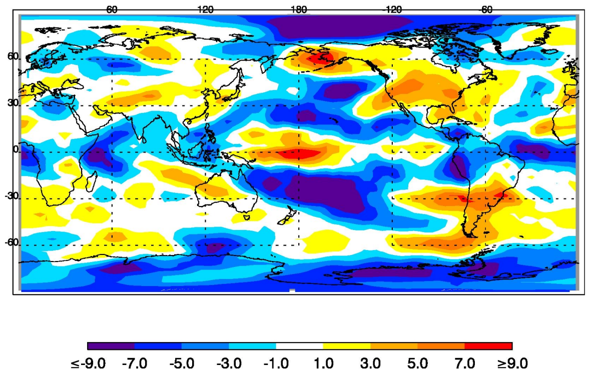
250-hPa Specific Humidity (g/kg)

Trend (Glo Mean: 0.004±0.003 g kg^{-1}/decade)



250-hPa RH (%)

Trend (Glo Mean: -0.9±1.2 %/decade)



ERA-5 indicates a larger decrease of relative humidity. These are from different amount of increase of specific humidity even though similar temperature increase is noted.

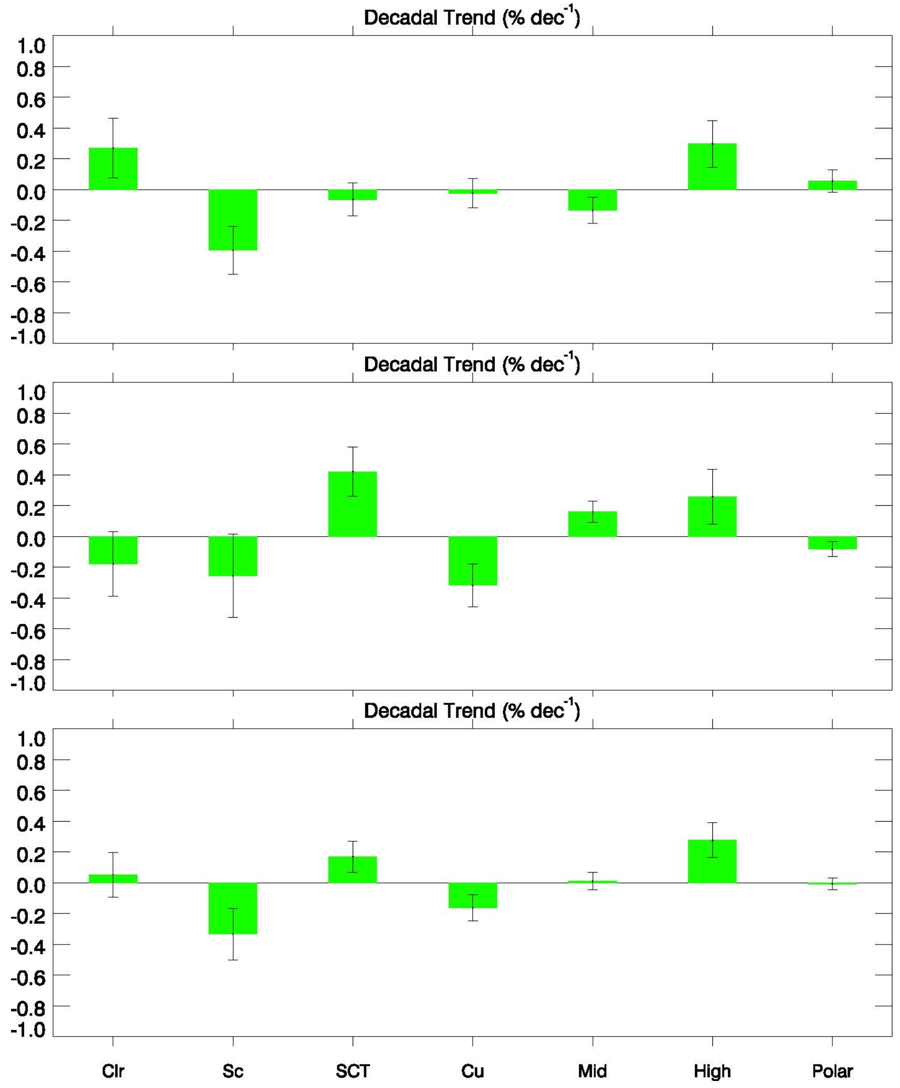
A Similar plot to what Norman showed in the last CERES meeting
(Should not be a final version; examination is ongoing)

MODIS Cloud Trend (%/decade)

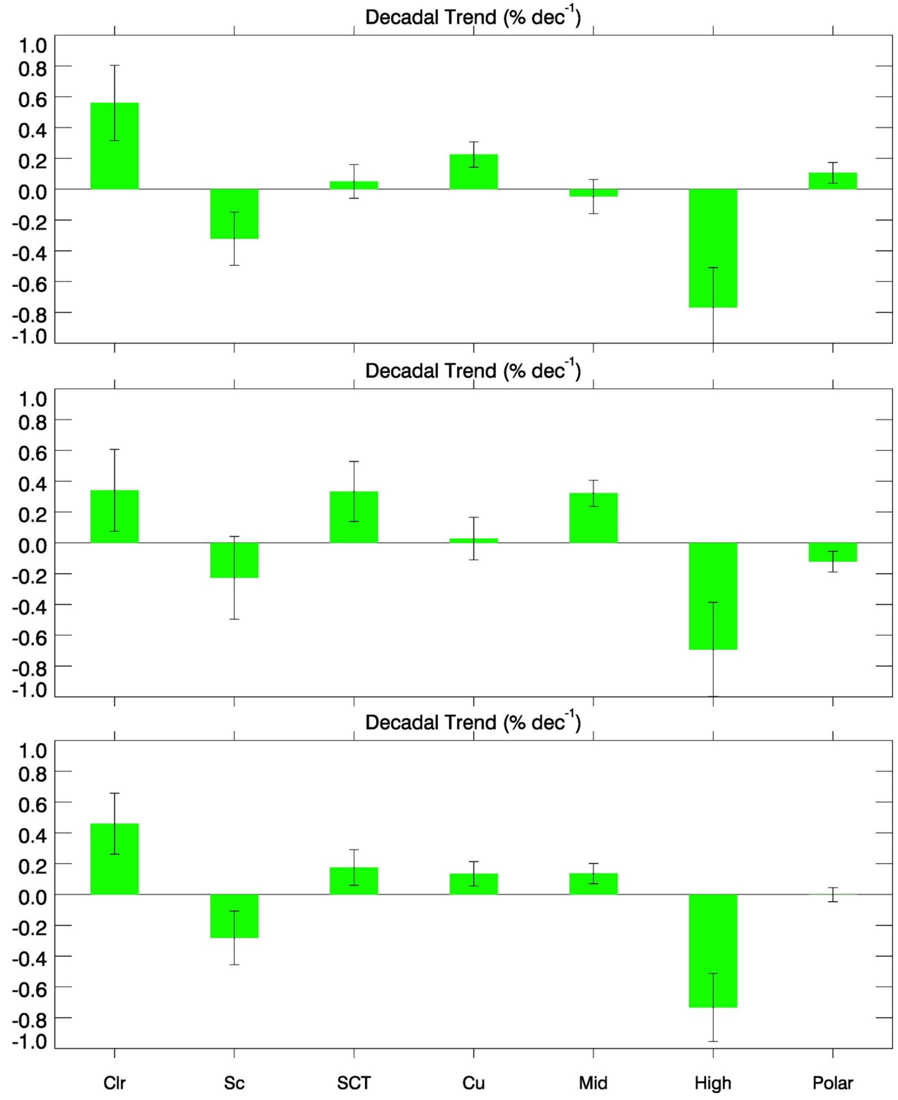
EQ-90N

90S-EQ

90S-90N



CALCS Cloud Trend (%/decade)



Conclusions

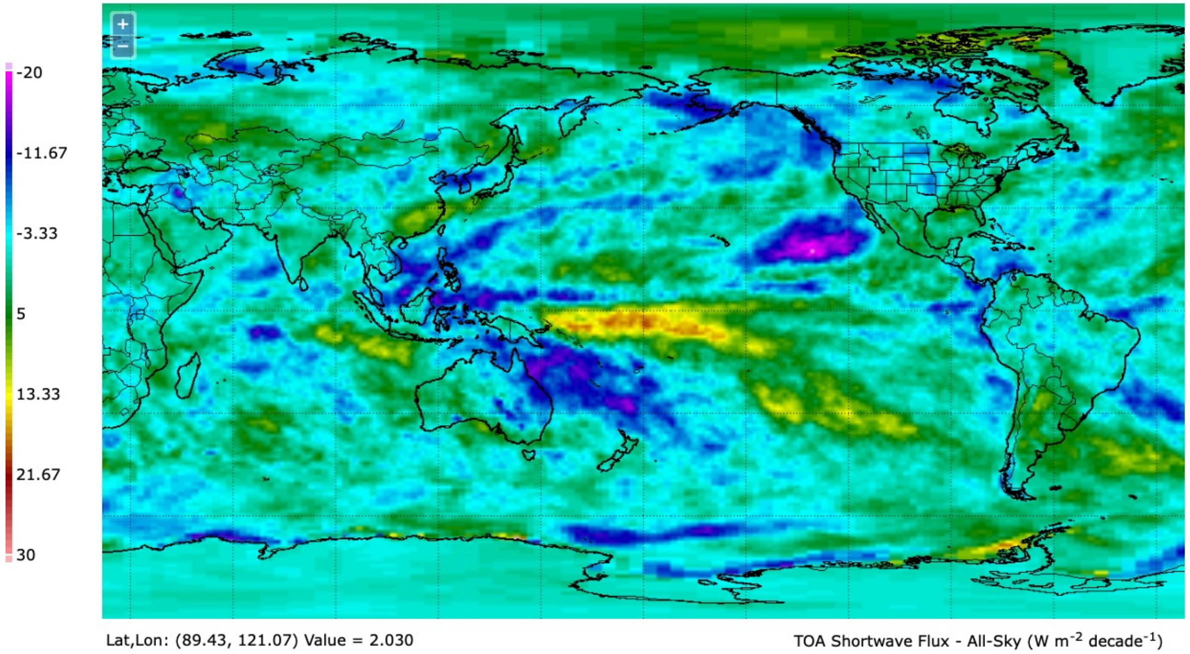
- For a short-term comparison, active sensors provide more accurate cloud vertical structures. MODIS underestimates high and low-level clouds and overestimates mid-level clouds. However, the differences are compensating and horizontal cloud coverages from MODIS are well agreed with CALCS.
- The use of CloudSat itself underestimates cloud amounts significantly, requiring further information from other sensors, such as CALIPSO. The CloudSat CPR sensor output power degradation can be mitigated using the threshold of $Z_{dB} \geq -25$ dBZ.
- CALIPSO shows a decreasing trend of high clouds, which is not observed by MODIS nor CloudSat. It might be due to 1) changes of optically thin cirrus clouds 2) CALIPSO sensor degradation, requiring further examination.
- Both MODIS and CALCS capture similar spatial distribution of cloud trends. However, CALCS indicates larger decrease of clouds over the SPCZ, mostly driven from CALIPSO information.

Thank you for your attention!

Any questions or comments, please contact to
seung-hee.ham@nasa.gov

EBAF 4.1

SW Trend 2007-2017



LW Trend 2007-2017